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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

A Note on the Output Noise of the D.C. Amplifiers in Tridac

by

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SUMMARY

The computing amplifiers of the TRIDAC flight simulator, as originally designed and installed, gave excessively large noise outputs. This memorandum describes an investigation into the noise levels in the machine and lists the modifications necessary to reduce the noise levels to an acceptable level.

1 General

An investigation was made to determine the cause of the excessive output noise of the d.c. amplifiers in Tridac. The various causes discovered are detailed here so that any future recurrence of the faults can be readily diagnosed. Modifications necessary to reduce the noise to an acceptable level are listed in an appendix.

An incidental result of the investigation was the discovery of a number of short circuits between the chassis and signal earth connections to each raft. The signal earth cables provide a zero potential reference to each raft; a short circuit to the chassis bleeds supply currents into these cables so that the reference potential is no longer zero. At present there are no indications when such faults arise and it is recommended that a monitoring circuit be installed as described in the appendix.

Table I gives a frequency analysis of the output noise of typical amplifiers before modification. The higher frequency components are, of course, beyond the frequency range of the recorders and plotting tables used in Tridac. However the amplitude of these components must be reduced, since they can produce low beat frequencies and condenser blocking; where high gains are involved, they also reduce the voltage range over which the d.c. amplifiers can operate without limiting. It will be seen that a number of the frequency components are of small amplitude; however the net effect when all components are present is an excessive noise level.

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Each of the components of the noise can be eliminated or reduced to negligible levels. The 300 and 2400 c.p.s. heater ripple can, however, only be eliminated at the expense of amplifier performance, since it is necessary to shunt a small capacitance across the feedback resistor. Normally it is only necessary to reduce this ripple where amplifiers are cascaded to give a high overall gain. It will be possible after effecting the modifications detailed in the appendix, to reduce the total noise level, as measured at the input grid of the d.c. amplifier to 5 millivolts peak to peak.

Some typical amplifier output signals before and after effecting the modifications are shown by the oscillograms of Figs. 1 and 2.

## 2 Detailed Analysis

### (a) 1 p.p.s. pulses

These pulses are due to switching transients (500 volts peak to peak) developed across the highly inductive coils of the Pullin relays on the control desk and programme unit; namely relays H and J. The transients are picked up by all amplifiers, particularly those in the control room.

The amplitudes of the pulses can be reduced by a factor of 20 by connecting a suppressor circuit across the relay coils, (see Appendix, item 6). This reduces the switching transients across the relay coils from 500 to 40 volts.

### (b) 1 p.p.s. pulses

These pulses are synchronous but out of phase with those described above. They originate from the 1 p.p.s. signal present on the stepping banks of the six drift monitoring uniselectors on each raft. Transient currents pass from here via the stray capacitance between adjacent banks on the unisector and then to signal earth. Voltage transients are thus established across the reactance of the signals earth cable.

These pulses are eliminated by the amplifier modifications detailed under 2(c). As a further precaution it is desirable to connect a capacitance, say 4 mfd, between signal and chassis earth, to short circuit any voltage transients that may develop there.

### (c) 0 to 15 c.p.s. sine wave

This is due to a beat frequency effect between the 400 c.p.s. supply voltage to the relay corrector and any one or more of the following:

- (i) an eighth harmonic of the 50 c.p.s. mains frequency
- (ii) a tenth harmonic of the mains frequency, particularly when the mains frequency is low and the chopper frequency high
- (iii) the 400 c.p.s. of the No. 2, 3 phase machine; this feeds the rectifiers which supply the -170 volt level heater current
- (iv) the 400 c.p.s. of the 120 volt, single phase machine; this supplies the magnetic modulator drift correctors.

These four frequencies are present in the small voltage between the signal and chassis earth connections at each raft. The input circuits to the corrector are referred to signal earth and the corrector amplifier to

chassis earth. The a.c. voltage between signal and chassis earth is therefore amplified by the corrector amplifier and chopped by its relay. The result of this is a beat frequency voltage at the output of the corrector and therefore of the d.c. amplifier. The output can have any beat frequency between 0 and about 15 c.p.s. Higher frequencies are blocked by the low pass filter in the output of the corrector.

The beat frequency can be reduced to a negligible level by connecting the first stage of the corrector amplifier to signal earth instead of chassis earth. This reduces the gain of the amplifier to signal earth/chassis earth voltages by the gain of the first stage. The signal earth cable serves as a reference and should not carry current. A resistor has therefore been added in the amplifier circuit; this bleeds a current from the -300 volt supply which is equal and opposite to that supplied to the first stage of the amplifier. These modifications are detailed in the appendix, items 1(b) and 1(c).

(d) 50 c.p.s. sine wave

This is due to mains currents flowing along metal frameworks, pipes and chassis wiring. The resultant voltage drop appears between chassis and signal earth at each raft. This voltage is amplified by the amplifier in the relay corrector as in (c) so that a 50 c.p.s. sinusoid as well as a beat frequency voltage appears at the output of the d.c. amplifier. The 50 c.p.s. sinusoid is attenuated by the filter in the corrector output but sufficient remains to produce the noise level quoted in Table I.

The 50 c.p.s. noise is also produced by the magnetic modulator correctors, since the output stage is connected to chassis instead of signal earth.

This noise can be reduced to a negligible level by connecting the first stage of the corrector amplifier and the output of the magnetic modulators to signal earth instead of chassis earth. See appendix items 1(b), 1(c) and 2(b).

A low level 50 c.p.s. noise component remains after modifying the correctors. This is because the d.c. amplifier stages are of necessity connected to chassis earth. However it is held to a negligible level by the normal amplifier feed back circuit and the action of the correctors.

(e) 100 c.p.s. rectified sine wave

This originates from a 100 c.p.s. ripple of 1 volt peak amplitude on the 24 volt d.c. supply. The 24 volts supply operates relays which select the required gain of the six amplifiers used with the Evershed and Vignole pen recorders. The voltage ripple across the relay coil is coupled via the relay contacts to the input wiring of the amplifiers. This noise can be eliminated by earthing the yokes of the relays.

(f) 200 c.p.s. sine wave

The alternating current supplied to the corrector relays is returned to the alternator via the chassis earth connection on each raft; this produces a 200 c.p.s. voltage between chassis and signal earth and a corresponding amplifier output. In addition the 200 c.p.s. currents to the relay coils leak across the valve bases into which the relays are plugged. The input grid of the amplifier is connected to this valve base and so picks up and amplifies a 200 c.p.s. voltage.

This noise can be eliminated by supplying the 200 c.p.s. current to the relays with twin wiring; the centre tap of the supply transformer being earthed so that the 200 c.p.s. voltage is balanced about earth. See appendix item 3.

(g) 300 c.p.s. sine wave

The source of this noise was traced to a short-circuit between the chassis earth and the earth side of the zero-level d.c. heater bus bars. This zero level d.c. heater supply is derived from a three phase 50 c.p.s. rectifier circuit so that the ripple voltage is at 300 c.p.s. The 300 c.p.s. signal developed between chassis and signal earth is amplified by the drift correcting amplifiers and thus appears at the output of the computing amplifiers.

(h) 300 p.p.s. pulses

This noise also comes from the 300 c.p.s. ripple on the heater supply. Heater current at this ripple frequency goes via the heater-to-cathode capacitance and leakage of all the valves concerned to chassis earth and so produces a 300 p.p.s. voltage between chassis and signal earth. The fault is accentuated if any heater-cathode faults develop on the valves concerned. This accounts for some of the noise; the remainder is due to stray coupling between the heater wiring and the connections to the input grids of the computing amplifier.

The level of the 300 p.p.s. noise quoted in Table I is for a computing amplifier connected with  $2M\Omega$  input and feedback resistors. The level is independent of gain but varies with the value of feedback resistance as shown in Table II.

It is not practical to smooth the existing heater ripple since currents of over 100 amperes are involved. The noise can however be reduced if necessary by shunting a small capacitance across the feedback resistance; a value of 47 or 100 p.f.d. is recommended. Table III shows how the noise varies with the values of feedback capacitance.

(j) 400 p.p.s. square waves

The source of this noise which is peculiar to raft 6 was traced to the two pulse amplifiers which supply timing pulses to the Evershed and Vignole pen recorders. The power amplifying valves in these units are oscillating at a frequency of 27 Mc/s and transmitting the oscillation to all the d.c. amplifiers via the signal earth bus bars which function as stub lines. The 27 Mc/s radiation is amplitude modulated by the operation of the corrector relays and detected and demodulated by the d.c. amplifiers.

The fault can be cleared by connecting "stopper" resistors to the anodes and grids of the oscillatory valves.

(k) 400 p.p.s. pulses

This noise arises when the output of the corrector amplifiers is large either as a result of excessive drift voltages (greater than 40 millivolts at the input) or as a result of the 50 c.p.s. voltage between chassis and signal earth. The output of the corrector amplifier is periodically shorted by the chopper relay. When the voltage to be shorted exceeds about 35 volts peak then an oscillatory discharge occurs at the relay contacts just before they make. This discharge radiates an impulse to the adjacent amplifiers.

The effect can be eliminated by connecting a 1000 ohm resistor in series with the output relay contact. This resistance functions as a "stopper" and damps the discharge. It should be wired as close to the relay contact as possible.

(l) 400 p.p.s. pulses

A number of monitoring amplifiers (K units) are wired incorrectly so that the corrector relay periodically shorts the chassis and signal earths at a frequency of 400 c.p.s. Any a.c. or d.c. voltage existing between chassis and signal earth is thus chopped into a 400 c.p.s. square waveform with large inductive peaks on the trailing edge of each square wave. These peak voltages, being between chassis and signal earth, are amplified by the d.c. amplifiers.

A faulty K unit would normally only effect one raft. However, the signal earth cables to the control room are loomed together and the capacitance between the cables is sufficient to couple the faults due to one K amplifier to all the rafts in the control room.

(m) 400 c.p.s. sine wave

This concerns the amplifiers corrected with magnetic modulators. The noise is inherent in the circuit design of the magnetic modulators since a compromise is necessary between two conflicting requirements for the input filter. The level of this noise is however negligible.

(n) 400 p.p.s. pulses

This noise is due primarily to peaky currents flowing through the relay coils connected in the output stage of the magnetic modulators. The relay coil amplifies and radiates the peaky signal to other amplifiers. The noise due to this can be eliminated by earthing the yoke and dust covers of the relay.

(p) 400 c.p.s. sine wave

This noise appears only on the amplifiers which supply the  $\pm 30$  volt references in each raft. The wiring between the terminal panels and the input grid of these amplifiers is not screened and runs close to four large a.c. heater transformers. The amplifier thus picks up the a.c. heater voltage. The amplifier connections should be replaced with screened wiring.

(q) 2,400 p.p.s. pulses

This noise originates from the 2,400 p.p.s. ripple on the -170 volt level heater supply, which is provided by a three phase 400 c.p.s. rectifier circuit. The same remarks apply to this noise as for the 300 p.p.s. ripple. The waveform is however more peaky so that the feedback condenser is more effective.

The noise has a higher level on rafts 8, 9, 10 and 11. This is because the chassis and signal earth cables are loomed with those carrying heater currents. The capacitive coupling produces an additional 2,400 c.p.s. ripple on the earth lines. The trouble can be remedied by opening the loom and re-laying the cables in separate groups.

(r) 4,000 c.p.s. pulses

This originates from commutation noise on the 24 volt rotary generator supply and as above is due to the earth cables being loomed with those carrying the 24 volt currents.

(s) 32,000 c.p.s. sine wave

This is a consequence of amplifier instability rather than noise. It concerns some amplifiers associated with the hydraulic servos and is due to inadequate screening of the wiring between the amplifiers and their gain controls; the latter being mounted on the front panels of the raft remote from the amplifiers. One of the connections from the output of the amplifier is screened unnecessarily and the fault can be cleared by interchanging this connection with the one requiring a screened wire.

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Attached

Appendix I  
Tables I to III  
Negs. Nos. 123.136 - 123.137

Distribution

CGWL  
GW(A)1(b)  
WRE (Australia) 12  
6 (Through GW(A)1(b))

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APPENDIX I

Modifications to Reduce Amplifier Noise in TRIDAC

1 Relay Correctors

- (a) replace 1 MFD coupling condensers with 0.02 MFD
- (b) connect first amplifier stage to signal earth instead of chassis earth
- (c) connect a 164 K $\Omega$  resistor between the -300 volt supply and signal earth
- (d) connect a 1,000 ohm resistor in series with the relay contact; that is direct to pin 2 of the base socket.
- (e) disconnect relay coil from earth.

2 Magnetic Modulators

- (a) earth yoke and cover of type 600 relay
- (b) connect output stage to signal earth instead of chassis earth
- (c) connect relay contact 1A to signal earth instead of chassis earth
- (d) connect an additional rectifier type Q8/1 with reversed polarity across MR1.

Modification (d) reduces polarising effects, not noise; it is included here to complete the current list of modifications for this unit.

3 200 c.p.s. supply

Replace existing supply transformer with one having a centre tap and earth the centre tap. As a temporary measure a dummy centre tap has been made by connecting two indicator lamps across the supply. This will give an indication of an earth fault on either side of the supply but does not protect the supply against such a fault.

4 Signal Earth Monitoring

Install a millivoltmeter on the control desk with a selector switch so that the potential of the signal earth connection to each raft, with respect to the generator room bus bar, can be measured.

5 ±30 Volt Amplifiers

This modification concerns the amplifiers which supply the J and JH units in each raft. The wiring between the front panels and the grid connection, (pin 1 on the signals socket) is unscreened. Replace these connections with screened wiring.

6 Pullin Relays

This modification concerns relay H on panel N of the control desk and relay J on the programme unit. Connect a suppressor circuit across the relay coils consisting of a Q8/2 rectifier in parallel with a 1 MFD capacitor and 100 ohm resistance in series.

7 Chassis/Signal Earth Condenser

Connect an 3 MFD paper condenser between chassis and signal earth on each raft.

8 Supply Cables in Servo Electronics Room

Re-arrange supply cables between rafts and generator rooms so that earth cables are not loomed with those carrying heater and 24 volt supply currents.

9 Raft 6, Cabinet 21

Earth the yokes and covers of relays A1 to A6 and B1 to B6.

10 Rafts 9 and 10

This modification concerns the amplifiers listed below. A wire running from the lower end of the gain control potentiometer on the front panel is unscreened; this makes the amplifier unstable. The connection from the top end of the potentiometer is screened unnecessarily. The two connections should be interchanged.

RAFT	CABINET	AMPLIFIERS
9	34	A15. A17.
9	35	A15. A17. A35. A37. A55. A57.
10	36	A15. A17. A35. A37.
10	37	A15. A17. A35. A37. A55. A57.

11 Rafts 9 and 10

This modification concerns the amplifiers listed below. The external wiring of these amplifiers is such that they are inherently unstable. A 47 pfd should therefore be connected across the feedback resistor in each case.

RAFT	CABINET	AMPLIFIERS
9	35	A13
9	35	A33
9	35	A53
10	37	A13
10	37	A33
10	37	A53

12 Feedback Condensers

Make 100 off each of 47 pfd and 100 pfd condensers which can be clipped across the standard amplifier feedback resistors as required to reduce 300 and 2,400 c.p.s. noise.

TABLE I  
Analysis of Output Noise

Note: Noise levels quoted are for amplifiers having  $2\text{M}\Omega$  input and feedback resistors, with the input earthed

Frequency (c.p.s.)	Waveform	Peak Volts (mV.)	Source	Remarks
a 1	spikes	10000	1 p.p.s. standard frequency	can be reduced by suppressing relays on control desk and programme unit
b 1	spikes	2000	1 p.p.s. standard frequency	can be reduced by modifying relay correctors and connecting condenser between chassis and signal earth
c 0 to 15	sine wave	50	various, see notes	can be reduced to a negligible level by modifying wiring of correctors
d 50	sine wave	30	230 volt a.c. mains	can be reduced to a negligible level by modifying wiring of correctors
e 100	rectified sine wave	30	ripple on 24 volt d.c. supply	on recorder amplifiers in raft 6 only; can be eliminated by screening relays
f 200	sine wave	30	20 volt 200 c.p.s. supply	can be eliminated by balancing 20 volt 200 c.p.s. supply
g 300	sine wave	30	ripple on zero level heater supply	due to earth fault on heater bus bars
h 300	spikes	70	ripple on zero level heater supply	can be reduced by shunting small capacitance across amplifier feedback resistor
j 4.00	square waves	150	27 Mc/s oscillation	on recorder amplifiers in raft 6; due to a faulty U unit, now corrected
k 4.00	spikes	2000	20 volt 200 c.p.s. supply	due to oscillatory spark discharge across relay contact in the relay corrector; can be eliminated by connecting a stopper resistance to relay contact
l 4.00	spikes	1500	20 volt 200 c.p.s. supply	due to faulty wiring of K unit, now corrected

TABLE I (Contd.)

	Frequency (c.p.s.)	Waveform	Peak Volts (Mv.)	Source	Remarks
m	400	sine wave	12	120 volt 400 c.p.s. supply	on magnetic modulator corrected amplifiers; cannot be eliminated
n	400	spikes	270	120 volt 400 c.p.s. supply	can be reduced by screening relays in magnetic modulators
p	400	sine wave	30	208 volt 400 c.p.s. supply	on all J units; can be reduced by screening input wiring to amplifiers
q	2400	spikes	70	ripple on -170 volt level heater supply	can be reduced by shunting small capacitance across amplifier feedback resistor
r	about 4,000	spikes	15	24 volt d.c. supply	due to capacitance coupling between earth cables and those carrying 24 volt supply; can be eliminated by re-laying cables in separate looms
s	32000	sine wave		very large amplifier instability	on particular amplifiers associated with hydraulic servos; due to inadequate screening of wiring going to gain controls on front panels of raft; can be eliminated by re-arrangement of wiring

TABLE II  
Variation of Heater Ripple Output with Value  
of Input and Feed Back Resistors

Input Resistance (Megohms)	Feedback Resistance (Megohms)	Output Ripple (Peak Millivolts)
2	0.1	30
2	0.5	80
2	1	110
2	2	120
0.1	2	110
0.5	2	110
1	2	110
2	2	120

TABLE III  
Variation of Heater Ripple Output  
with Value of Feed Back Capacitance

Feedback Resistance (Megohms)	Feedback Resistance (Megohms)	Feedback Capacitance (Picofarads)	Output Ripple (per cent)
2	2	0	100
		15	60
		33	37
		47	30
		100	17
0.1	0.1	0	28
		15	24
		33	17
		47	15
		100	10

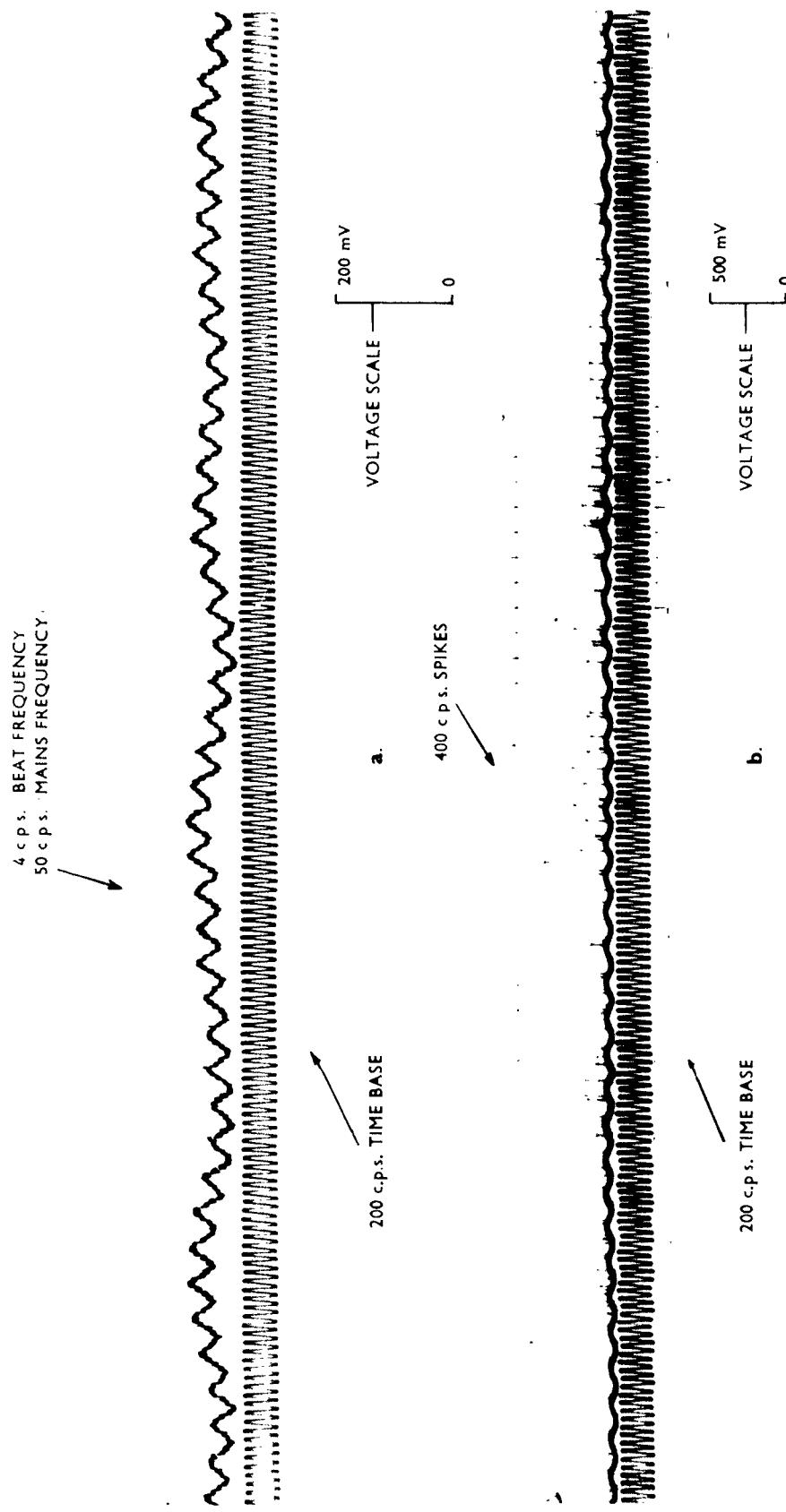


FIG.1. TYPICAL AMPLIFIER OUTPUT NOISE BEFORE MODIFICATION

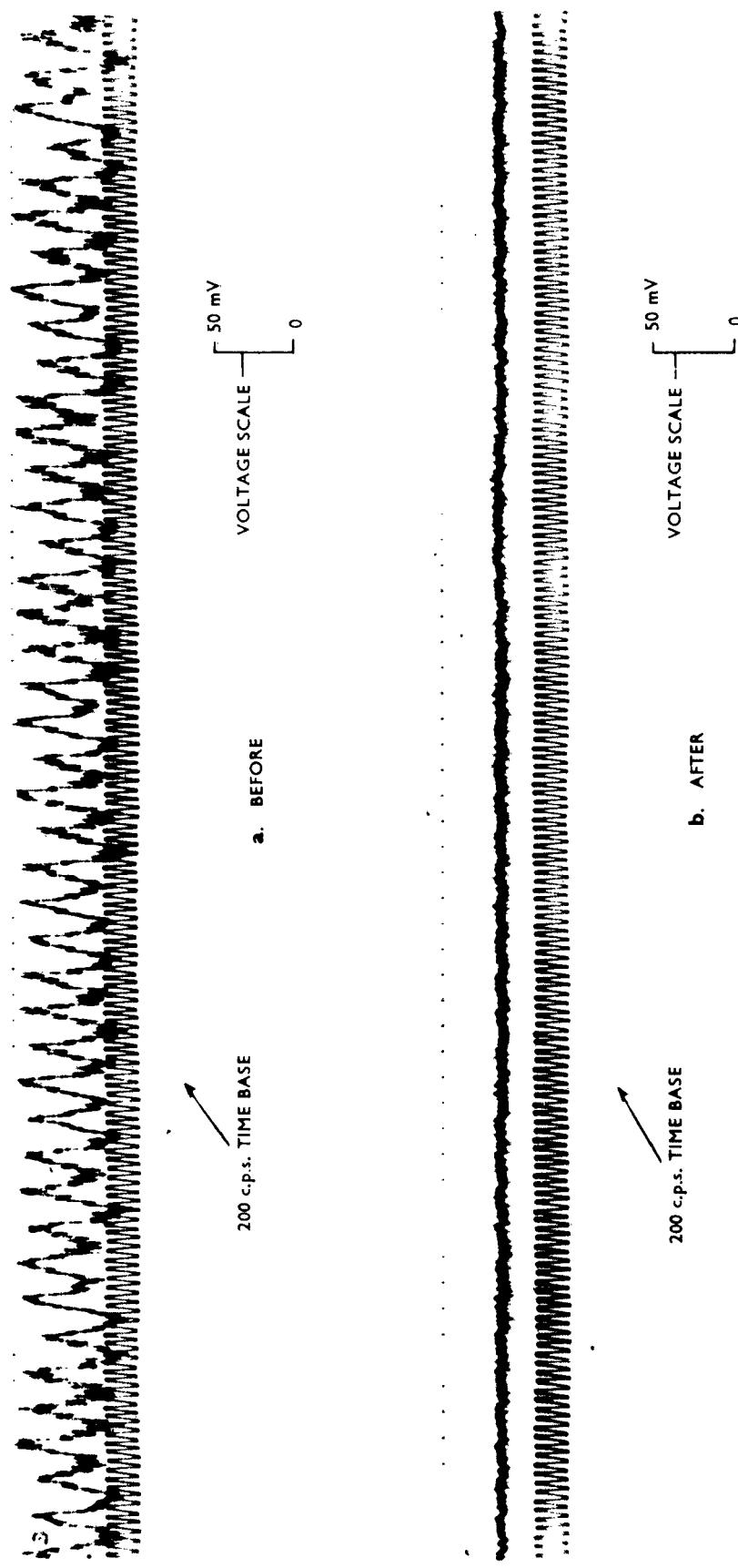


FIG.2. TYPICAL AMPLIFIER OUTPUT NOISE BEFORE AND AFTER MODIFICATION



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